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Developing affordable and sustainable housing through energy, transport and building utility integration

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ABSTRACT

Housing affordability and sustainable development are not polarised ideologies as both are necessary with increasing urbanisation. We must bridge the gap between current median house pricing and target affordable house pricing whilst pursuing sustainability. This paper examines the potential of initial construction cost and ongoing utilities and transport cost reduction through the integration of sustainable housing design and transit oriented development principles in a Commuter Energy and Building Utilities System (CEBUS). It also introduces current research on the development of a Dynamic Simulation Model for CEBUS applications in the Australian property development and construction industry.

Introduction

Housing affordability is a worldwide concern. For example, recent research in the United Kingdom has shown increasing housing prices in response to government intervention in financial markets designed to fuel ongoing growth in the economy (Mulliner & Maliene, 2013). Research in the US has also demonstrated a link between declining public health and increasing problems with housing affordability (Pollack et al, 2010) whilst housing costs in Brazil have continued to increase despite over 20% of inner city land area in Sao Paulo remaining vacant (Sperandelli et al, 2013). Currently, high prices in housing markets around the world are set against a backdrop of continuing efforts in developing sustainable housing through innovative designs, materials and systems. “Eco” homes aim to balance the issues of climate change, resource use and quality of life (Prickett & Bicknell, 2009). Adaptive re-use of existing buildings is being promoted as a means of reducing the use of new materials in sustainable housing developments (Yung et al, 2013). However, few of these sustainable homes are available at or below target affordability price points (HIA, 2012).

There has been extensive advocating for sustainable housing guidelines and planning schemes by governments, professional associations and academia. Some have shown potential, such as transit oriented development (TOD) whereby rail stations are located within pedestrian walking distance from new housing developments (Zhao & Deng, 2013) together with greater use of higher density strata and community title (S&CT) developments, which have reduced per capita energy consumption and carbon emissions (Norman et al, 2006). However to date, the building industry has failed to deliver sufficient stock of sustainable yet affordable housing as evidenced by the emergence of non-government housing organisations such as “Habitat for Humanity”, who are actively working to provide clean, affordable and sustainable housing for the estimated 100 million homeless people around the world (Habitat, 2010). At the same time, utilisation of public transport has actually declined in many countries, including Canada, the USA and Australia, to under 10% of the population. This has resulted in sharp increases in traffic congestion, carbon emissions and household transport costs when compared with 1990 levels (Gipton, 2009). Increased investment in tollways and tunnels has actually increased car usage as a result of improved average trip speeds thus further contributing to the decline in public transport patronage around the world (Chen, 2013).

The issue of affordability is seen as a major barrier to increased uptake of sustainable housing construction. Many assume sustainable housing is more expensive to execute when compared to standard practices and that more sustainable options are therefore not financially viable (Pitt et al, 2009). At the same time, the perception that sustainable transportation methods act to restrict personal mobility is another major barrier to be overcome before we see an increased uptake of genuine sustainable housing construction that incorporates sustainable transport methods (Delucchi & Kurani, 2013).

Accordingly, the property industry is seeking new development guides and frameworks which can integrate affordability considerations with sustainability measures. They also need tools that can help turn the conflicting demands of affordability, reduced environmental impact and improved mobility into saleable housing stock for the mainstream market. This paper presents the interim results of a research project aimed at identifying potential savings in up-front construction cost and ongoing utilities and transport costs available through the integrated application of best practice in sustainable construction and transit oriented development strategies. It identifies the knowledge gaps in current research on affordable and sustainable housing development methods. A case study methodology is used to explore and develop the necessary ingredients of a pilot Commuter Energy and Building Utilities System (CEBUS), which will assist in providing a balance between housing affordability and sustainability. A Dynamic Simulation Model and a conceptual framework are brought forward using data from survey of strata and community title development residents so as to guide in-depth interviews of industry stakeholders as the next step in the research program.

Study of Related Literature

Rapid urbanisation in many parts of the world has pushed housing demand to new heights while the ongoing Global Financial Crisis further jeopardises housing affordability. Table 1 shows the government endorsed housing affordability threshold against household gross income (ULDA, 2009). In the December quarter 2011, the median purchase price for houses in Brisbane, Australia reached A$499,000 (REIQ, 2012) against the average household gross income of A$61,730 (Payscale, 2012). This equates to a multiple of gross income of 8 times compared with the 5 times maximum in Table 1.

Table1: ULDA Household Gross Income and Affordable Housing Thresholds

As the first research step, a desktop review on housing development, market pricing issues and sustainability based design and construction was carried out. The focus was on identifying those elements that can potentially provide reductions in initial construction cost and life cycle operating costs without jeopardising environmental and social outcomes.

Sustainable housing design uses a wide range of passive and active design principles and practices to improve environmental and social aspects. For example, significant life cycle cost benefits can be achieved through strong passive building design (Chaturvedi, 2008). Research into the impact of best practice passive design using cross-ventilation has shown a reduction in energy usage of 50% when compared with standard per capita energy usage (Miller, 2007). Development of district scale ñmicroclimatesò has also contributed to improved urban comfort without the need for active cooling systems (Triantis et al, 2011). ñGreen urbanismò is another sustainable design concept that has been developed to combat rapid urban growth through the move towards closed-loop, rather than linear, utilities infrastructure metabolisms for housing estates (Codoban & Kennedy, 2008). Examples such as integrated rainwater harvesting and stormwater management systems have provided capital cost savings of up to 50% and ongoing potable water operating cost reductions of up to 75% (Reidy, 2008). In Europe, study of closed loop design philosophies was undertaken at developments such as ñEVA Lanxmeerò at Culemborg in The Netherlands. The interconnection of different city cycles, such as sanitation, energy and food production, has demonstrated how the built environment can act as a ñparasiteò to harvest effluent to create low cost energy for the inhabitants and fertilizer for growing crops. (Timmeren & Sidler, 2007). Decision support systems have also been developed to assist with the design and costing of municipal ñgreenò infrastructure using closed-loop design principles for urban agriculture projects on vacant public land so as to reduce up-front and life cycle costs of food production (Kirnbauer & Baetz, 2014). Accordingly, passive and closed loop design was nominated as the first key element of a proposed new sustainable development model that offers both construction and life cycle operating cost reductions with improved environmental outcomes.

Additional first capital and life cycle cost benefits are possible through the use of virtual design technologies. These allow housing designers to develop and test building solutions with confidence in building constructability and long term operational performance (Bailey & Brodkin, 2008). Information and Communication Technology (ICT) has improved construction industry productivity, bridged gaps in communication between stakeholders and encouraged the implementation of new processes resulting in reductions of up to 25% in design time (Isaa et al, 2007). Furthermore, use of ICT has enabled planners to assess the social and environmental impacts of various sustainable design options at the regional level in order to help develop protected areas between cities (Wang et al, 2013). This Building Information Modelling (BIM) process allows project teams to quickly and accurately assess green building credentials for various material, equipment and systems selections (Barnes, 2009). Additional initial construction cost reductions are offered through linking BIM techniques to housing prefabrication. This involves constructing housing structures and key sub-components in a controlled factory environment before transferring them to their final destination for assembly. The benefits of off-site manufacturing (OSM) include a reduction in embodied energy and material waste, together with reduced construction costs of up to 12%, through improved constructability and reduced costs for major sub-components such as heating, ventilation and air-conditioning (HVAC) systems (Meiling et al, 2012). The combination of BIM and OSM was therefore nominated as the second key element of a proposed new sustainable development model that offers both construction and life cycle operating cost reductions with improved environmental outcomes and green building ratings.

Incorporating sustainable design principles into new homes and housing estates can also attract new economic models to help reduce first capital and ongoing debt servicing costs. Density bonuses are changes to a higher unit yield, whilst tax breaks/credits and/or direct financial grants can be provided to developers in return for achievement of a minimum specification sustainability rating. Research into factors that have led to an increase in sustainable housing development in the US has shown that these economic incentives are the main determinants for government regulators to consider in trying to encourage more affordable and sustainable housing development (Sauer, 2009). Increased use of distributed utility systems in accordance with ñgreen urbanismò principles, such as combined rainwater harvesting and stormwater management systems, has also provided opportunities for deployment of the Design, Build, Operate and Maintain (DBOM) method of project delivery and financing. A single contract is awarded for the design, construction, operation and maintenance of discrete items of utility plant in return for a defined user-pays fee over a fixed period (Dahl et al, 2005). Strata and community title developments have also demonstrated the ability of the body corporate to establish a ñuser paysò system based on DBOM contracts to recover the cost of capital equipment over its economic service life, rather than having the entire cost of the equipment paid for up-front by the developer / first home owner. This mechanism has been used by developers to remove capital equipment purchase costs from the homeõs selling price for items such as hot water systems, air-conditioning, water treatment systems, electrical switchboards and utility meters (Warnken, 2009). It has also been utilised by municipalities to help remove the capital cost burden of major public transport infrastructure from tax payers and transfer the costs to the end-users of the transport system (Warren & Kunczynski, 2000). The resultant reduction of up-front land and utilities and transport infrastructure cost per house provided by these financial incentives and DBOM contracts can be combined with the preceding sustainable design principles to provide further reduction in initial construction cost for new housing developments, hence they were nominated as the third key element of a proposed new sustainable development model that offers both construction and life cycle operating cost reductions with improved environmental outcomes.

Research into the benefits of locating new housing estates close to public transport nodes using the transit oriented development strategy has shown potential for reduced costs in personal transport of up to 75% (Rat, 2002). Studies conducted in major international cities including New York, London, Paris, Munich and Tokyo have demonstrated that public transport utilisation is positively correlated with increases in urban density. This study supports current international best practice of using higher density residential strata and community title schemes for the development / redevelopment of cities as a means of increasing public transport patronage (Wang, 2006). By locating new developments near public transport nodes, developers are typically offered a reduction in car parking requirements per occupant which in turn provides for improved yield and a resultant reduction in the land cost per house (City of Fremantle, 2011). Study of low-income housing programs has also shown that proximity to mass public transport schemes is a key determinant of the likely success of such programs (Duarte & Ultramari, 2012). Accordingly, the Transit Oriented Development strategy was nominated as the fourth key element of a proposed new sustainable development model that offers both construction and life cycle operating cost reductions with improved environmental outcomes.

One of the key life cycle cost benefits observed in strata and community title developments is the ability of the body corporate to purchase and on-supply services to both the common areas of the community and individual residents. These services have ranged from provision of utilities such as electricity, gas, water and broadband communications through to maintenance of the grounds or provision of a community recreation centre. By aggregating demand for these services across the entire community, savings of at least 20% have been achieved when compared with direct provision of the same services to individual residents and owners in common (Tucker, 2004). Use of advanced modelling tools designed to deal with the uncertainty of community scale utilities systems has also enabled a reduction in up-front capital costs for utilities infrastructure which has translated to lower capital cost per house (Lin et al, 2010). This demand aggregation model has also provided transport services via community owned boats in coastal developments and community owned shuttle vehicles at strata resorts, industrial parks and retirement villages. The resident manager or volunteer driver assists residents, guests and staff with airport transfers and connection with public transport nodes. This concept of community vehicle pooling and/or sharing has successfully demonstrated a reduction in private vehicle ownership costs for residents at The Waterfront strata and community title development in Sydney, Australia (The Waterfront, 2010). The resultant reduction in personal utilities and transport costs offered through utilities and transport demand aggregation can be combined with preceding sustainable design principles such as DBOM contracts for utilities and transport infrastructure to provide further reduction in initial construction cost for new housing developments, hence it was nominated as the fifth key element of a proposed new sustainable development model that offers both construction and life cycle operating cost reductions with improved social outcomes.

The integration of technologies such as building power systems and sustainable transport equipment using hydrogen fuel cells has also reduced household utilities and personal transport costs. The Honda Clarity vehicle is powered by hydrogen gas which is converted into electricity to drive electric motors with zero emissions. A "Home Energy Station" uses sunlight to produce hydrogen for the Clarity vehicle from rain water with surplus hydrogen being used in a stationary fuel cell to produce electricity and hot water for the home (AHMCI, 2009). Another example of such technology integration is The Hammarby Sjostad development in Sweden which consists of 11,000 apartments and 35,000 work places with 25,000 inhabitants, where the wastewater system collects biosolids to produce biogas for home heating, cooking and powering local compressed biogas shuttle buses and car pool vehicles. Approximately one third of the town's residents are members of the car pool which is booked via the internet and supplemented by public transport options such as tram, bus and water taxi. Hammarby is used as the model example of the Swedish "SymbioCity" concept which promotes holistic and sustainable urban development through finding synergies in urban functions and unlocking their efficiency and profitability (Kenter, 2007). The final example of the Fairfield Multi-Modal Transportation (MMT) Centre in the USA has solar photovoltaic (PV) panels on the façade to assist with building energy use whilst providing charging facilities for private and community owned electric vehicles and acting as a node for public bus services. The MMT concept is based on commuters taking their battery electric vehicle (BEV) from home to the centre where they can then take the public bus service to work whilst their vehicles are recharged from the solar PV system during the day (McDonald, 2009). Recent recognition of the fact that total building energy efficiency should be measured across both stationary and motive power metrics supports the use of such integrated technologies (Weigel, 2014). These integrated technologies can be combined with the preceding sustainable design principles such as transit oriented development strategies to provide further reduction in initial construction cost for new housing developments, hence they were nominated as the sixth and final key element of a proposed new sustainable development model that offers both construction and life cycle operating cost reductions with improved social and environmental outcomes.

Criteria and Challenges of Developing Integrated Commuter Energy and Building Utilities Systems

The Integrated Project Delivery (IPD) method provides the opportunity to design, build and operate new housing facilities as cost-effectively as possible through formation of collaborative and productive teams from all sections of the design and construction supply chain (AIA, 2007). This integrated development approach also allows for community attitudes and environmental conditions to be considered as part of the overall design optimisation process (Mani et al, 2005). At the same time, “lean” construction methods using value stream mapping (VSM) techniques have been used to support the IPD method by reducing design waste and delivering first capital cost savings of up to 18% (Goldstein, 2003). These combined methods were therefore suggested as the central control mechanism for combining each of the preceding individual best practice sustainable design elements in order to provide a new integrated sustainable development model as shown in the concept diagram in Figure 1. This model may reduce initial construction cost and ongoing utilities and personal transport operating costs and potentially bridge the gap between current median house pricing and affordable housing price targets as detailed in Table 1.

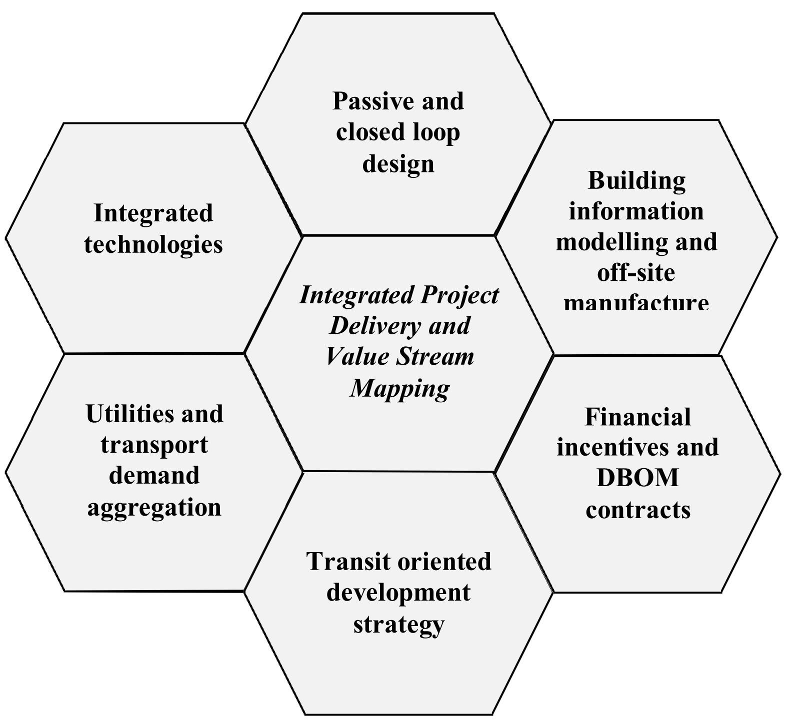


Figure 1. A new integrated sustainable development model

This proposed integrated development model was then applied to the local median house price example of A$ 499,000 using a typical “green” finance rate, together with typical annual personal utilities and transport expenditure, in order to quantify the potential savings results. A typical twenty (20) year “green” loan interest rate of 5.5% (Bendigo Bank, 2013) was applied to the average South East Queensland household utilities spend of A$1900 pa (Miller, 2007) and average personal transport spend of A$4500 pa (Travel Smart, 2010) to derive the net present value (NPV) of the potential savings offered by the proposed integrated sustainable development model, which are detailed in Table 2:

Table 2: Total effective first capital cost saving from the proposed integrated development model

This means that integration of current best practice sustainable design elements as detailed in the preceding literature review can potentially assist with the provision of affordable housing for household gross incomes in the upper band as shown in Table 1 through a theoretical 35% reduction of the $499,000 median house price to a $321,908 effective first capital cost. Further research is, however, required in order to identify new integrated design methods to help deliver affordable and sustainable housing at the $203,00 to $251,000 price points from Table 1 as required for the lower and medium income bands respectively. Accordingly, a visual representation of previous local and international research into affordable and sustainable housing development was then prepared as shown in Figure 2 which highlighted current knowledge gaps as potential focus areas for the next stage of the research program.

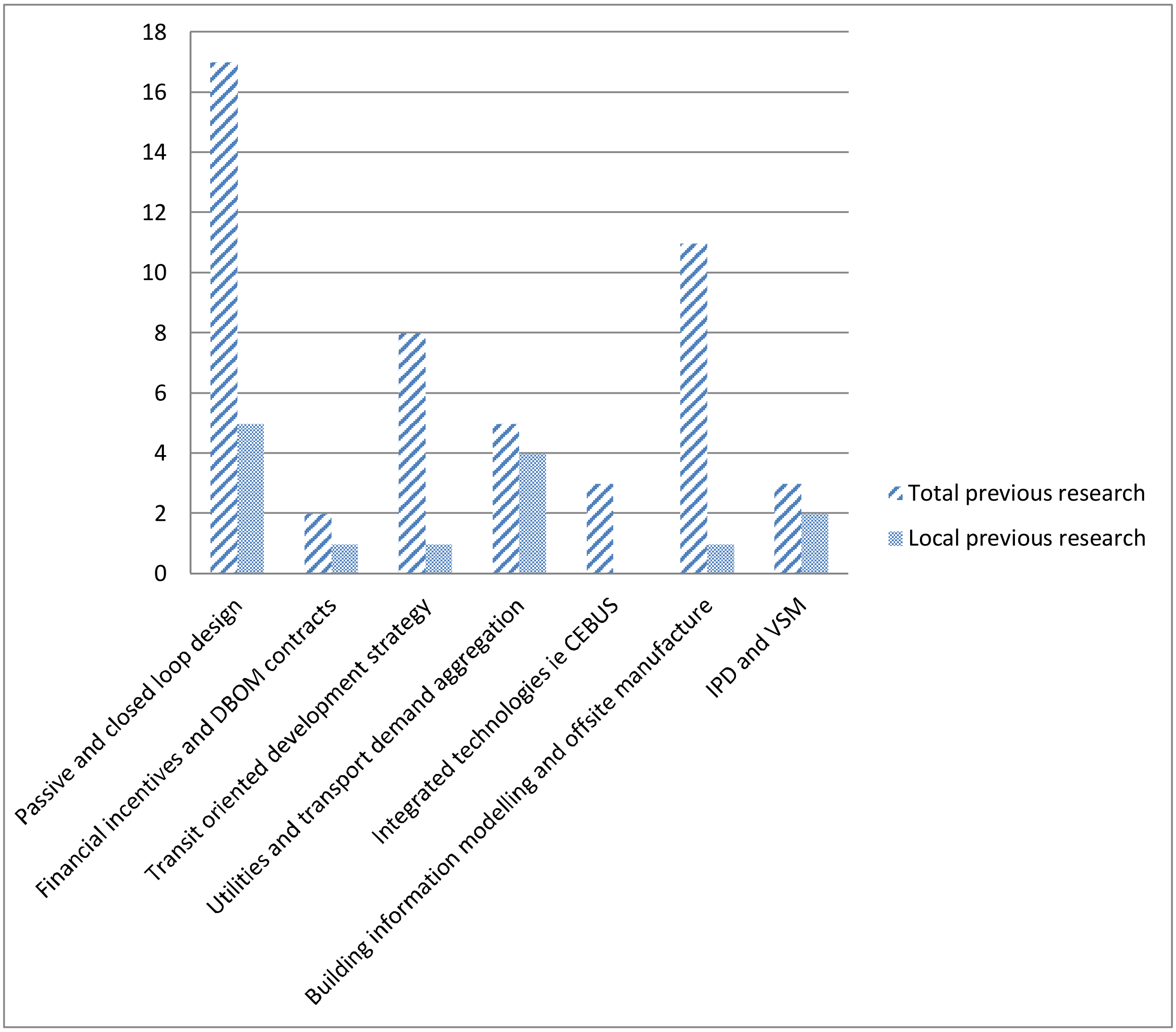


Figure 2. Indicators of previous research in affordable and sustainable housing

This chart highlighted that there has been no study in the Australian context of integrated technologies such as integrated building utility and transport energy systems (Commuter Energy and Building Utilities System or CEBUS) as a possible means of contributing to the development of affordable and sustainable housing. This was therefore proposed as the focus area for the next stage of the research program based on the following questions:

- Can integrated building utility and transport energy systems (CEBUS) contribute to affordable sustainable housing development in South East Queensland and;
- How can this contribution be tested and verified?

A further critical document study of key design elements related to the proposed CEBUS method was then undertaken covering the following topics:

- building integrated renewable energy generation systems;
- renewable energy based transport systems;

- software for renewable energy system design and transport survey;
- best practice in community vehicle sharing and/or pooling schemes and;
- potential regulatory barriers to uptake of the proposed CEBUS method.

Building integrated renewable energy generation systems

Active building integrated renewable energy generation systems such as solar PV arrays, solar hydrogen fuel cells and biogas generators offer both life cycle cost and environmental benefits:

- Solar PV arrays generate electricity through exposure to sunlight with very little aversive environmental effects such as pollution or waste. Current increases in solar PV cell efficiency of over 40%, together with reduced manufacturing costs, thin film PV polymers for glazing or roofing integration and rapidly increasing grid electricity costs, have resulted in increasing application of this technology in the housing industry (Bullis,2008);

- Solar hydrogen fuel cells use solar PV to electrolyse water into hydrogen, which can then be stored and used when required, unlike solar PV which is available during sun hours only. The stored hydrogen is then fed into a stationary fuel cell which creates electricity and hot water as a by-product (Manley & Rose, 2009);

- Use of household effluent, green waste and food scraps to produce biogas is emerging as another possible solution for the provision of building integrated renewable energy generation systems. A compact biodigester unit generates biogas which is then used directly for cooking and to supply small scale reciprocating engine generators which produce electricity for light and power, together with hot water and cool air via absorption chillers (Lampe et al, 2009).

In each of these examples, the comparative cost with coal based grid electricity is drastically improved if a cost is assigned to carbon emissions either via a direct tax or an emissions trading scheme. The equivalent cents/kWh cost of electricity generated from solar PV, fuel cell or biodigester systems may approach grid parity under these circumstances. (McKinsey & Company, 2008).

A summary of the typical maximum payback period, when compared with coal based grid electricity and the relative greenhouse gas (GHG) intensity for each of these preceding building integrated renewable energy generation systems, is shown in Table 3 (Newton & Tucker, 2009):

Table 3 Maximum payback period and relative GHG intensity for building integrated renewable energy systems

Table 3 highlights the fact that from both an economic and environmental viewpoint, the biodigester based CEBUS would appear to be the best option when compared with the solar PV and solar hydrogen fuel cell types.

Renewable energy based transport systems

Renewable energy based transport systems such as the battery electric vehicle (BEV), the fuel cell vehicle (FCV) and the compressed biogas vehicle (CBV) have also been highlighted as a possible way to help reduce personal transport costs and carbon emissions:

- The battery electric vehicle sources all of its energy from on-board electricity and is charged from the mains grid using renewable power where possible. The battery electric vehicle requires a significant trade-off between cost and range, with a typical 160 km range being the ideal from both a weight and cost perspective (Nissan, 2009).

- The fuel cell vehicle uses a proton exchange membrane (PEM) fuel-cell system to power an electric motor in a series hybrid configuration. The battery characteristics are based on the same high power lithium-ion battery used for conventional hybrid vehicles. On board hydrogen storage is achieved via solid, chemical or gaseous means and can be sourced from solar PV electrolysed rain water (Toyota, 2009).

- The compressed biogas vehicle uses a modified internal combustion engine (ICE) that operates on biogas produced by household effluent, green waste and food scraps feeding a compact biodigester unit assuming a typical daily black water production rate of 50 litres per capita and a typical dwelling population density of 2.5 persons per unit (Rajendran, 2012).

A summary of the first capital cost and greenhouse gas intensity relative to internal combustion engine vehicles for each of the preceding renewable energy based personal transport options is shown in Table 4 (Bandivadekar et al, 2008):

Table 4 Relative cost and GHG intensity for personal renewable transport systems relative to conventional ICEõs

Table 4 highlights the fact that from both an economic and environmental viewpoint, the compressed biogas vehicle based CEBUS appears to be the best option when compared with the battery electric vehicle and fuel cell vehicle types noting that the greenhouse gas intensity of these types is determined by the source of electricity used to charge the vehicle in the case of the battery electric vehicle or electrolyse water to create hydrogen in the case of the fuel cell vehicle. If coal based grid electricity is used in either of these scenarios then the compressed biogas vehicle based CEBUS remains the best option. If lower greenhouse gas intensity renewable energy is used for either of these scenarios then this relativity will change.

Software for renewable energy system design and transport survey

A detailed review of energy simulation software, available both commercially and via previous academic research projects, was then conducted for solar PV, biogas and hydrogen based renewable power generation systems, together with transport engineering software for survey of rail and bus commuter vehicle usage and costs as shown in Table 5 so as to help to identify the ôbuilding blocksö available for development of a Dynamic Simulation Model for testing the potential savings available from the proposed CEBUS method :

Table 5 Renewable energy simulation and transport survey software availability

Table 5 highlights the fact that there is a wide range of readily available software for developing the CEBUS Dynamic Simulation Model together with a range of transport survey software that can be utilised for capturing and analysing commuter trip data during the proposed strata and community title development CEBUS test phase of the research.

Best practice in community vehicle pooling and share schemes

Urban congestion has been cited as one of the major social and economic issues in cities around the world as a result of continued urbanisation. An integrated approach to solving congestion has been recommended, based on complementary actions between government, business, public transport commuters and road users (Schrank et al, 2010).

Carpooling represents one of many possible alternatives to single occupancy vehicle use for travel to work, school or public transport nodes. Recent study of carpool formation in Canada has suggested the following best practice elements (Buliung et al, 2009):

- A web based application is required to facilitate connection between potential car poolers
- The regional transport planning authority needs to coordinate the carpool scheme
- Interface of carpool participants with the local public transport system needs to be maximised
- Carpool time matches need to be optimised by postcode for ease of use
- Flexibility needs to be built-in for variable commuting patterns at the home-end of work travel

By following these best practice elements the carpooling uptake has reached 10% with reported benefits including an increased sense of community amongst participants. Other studies have shown that carpooling is particularly attractive for lower income bands and female employees who are concerned about poor security on public transport options (Zhou, 2013).

Another possible alternative to single occupancy vehicle use for travel to work or school is car sharing, which is an alternate system of car ownership, access and use as follows (ThinkingTransport, 2010):

- Private companies offer paid membership which allows people to take and use a number of vehicles when and as needed
- These self-service cars are available twenty four hours a day and are typically distributed over a wide urban area
- Employer hosted schemes using on-site vehicles have been found to work better than municipal schemes which typically use on-street vehicles (Collura, 1994)

Accordingly, the use of these best practice carpooling and/or car sharing strategies, in conjunction with the preceding renewable energy based building power and transport systems as part of the proposed CEBUS method, may help to further reduce personal transport costs, thus improving the affordability of new housing developments, whilst at the same time reducing greenhouse gas emissions and improving social outcomes via reduced traffic congestion.

Potential regulatory barriers to CEBUS uptake

Strata and community title developments appear to represent strong potential for deployment of CEBUS because there is an extant legislative framework that supports the governance and management of such systems in all Australian states and territories. The uptake of CEBUS within these communities may however be impeded by various government regulations. Accordingly, a review of the regulatory framework surrounding the proposed operation of CEBUS was undertaken as shown in Table 6 in order to help guide the required compliance for the proposed strata and community title development test site:

Table 6 Regulatory framework related to CEBUS operation

Table 6 highlights the fact that a clear set of Federal and State regulations exist for each CEBUS type to comply with hence there appears to be no initial regulatory barriers to the proposed deployment of a CEBUS test at a local strata and community title development.

Research Method and Development

Following completion of the initial desktop research and document study, further investigation was then undertaken to develop a suitable research methodology so as to ensure coherence and complementarity between:

- the affordable and sustainable housing problem facing the construction industry;
- the hypothesis regarding potential contribution of the CEBUS model; and
- the findings of previous research that support and inform this model (Fellows & Liu, 2008).

The first consideration in the research methodology development process was the context in which the proposed research will take place. The fact that the researcherõs interests, expertise and experience have contributed to the identification of the research problem and formulation of a hypothesis will impact on the proposed work and its results as will the very fact that research is being carried out (Popper, 1989).

Next, due consideration was given to environmental variables which may influence the research results through impact on recorded data together with subject variables ï dependent, independent and intervening - associated with the topic of study. This helped to guide design of the research methodologies so as to isolate the dependent variables from the environmental or contextual variables as shown (Baron & Kenny, 1986).

Having considered the context in which the proposed research is to take place together with the environmental variables, the issue of objectivity, being, ñthe degree to which different observers or judges are able to record the data in the same mannerò was considered next. This ensured that the data is not substantially influenced by the subjectivity of the observer (Drenth, 1998).

A review of historical antecedents to the development of knowledge also guided the research methodology development process, calling on Aristotleõs inductive-deductive method in which scientific explanation is defined as a transition from knowledge of a fact to knowledge of the reasons for the fact (Losee, 1993).

A final consideration in the research methodology development process was recognition of the current construction industry paradigm that sustainable housing development cannot be achieved in parallel with affordable housing development. It was therefore recognized that the proposed research methodology must ensure independence from this prevailing theoretical framework, so as to allow for original contribution to knowledge and a potential paradigm shift (Kuhn, 1996).

Next, specific research methods were considered, commencing with a review of successful empirical research methods used in construction industry research, which highlighted case studies, simulation, stochastic modeling, participant observation and experiments as the methods of choice for this research project (Remenyi et al, 1998).

Previous local research conducted in the strata and community title industry on managing major repairs and utilisation of decentralised water management systems, also recommended that a mix of on-line surveys and in-depth stakeholder interviews be employed in this research project (Easthope et al, 2009).

Based on the study of research methodologies and research planning, the overall research approach was developed as shown in Figure 3.

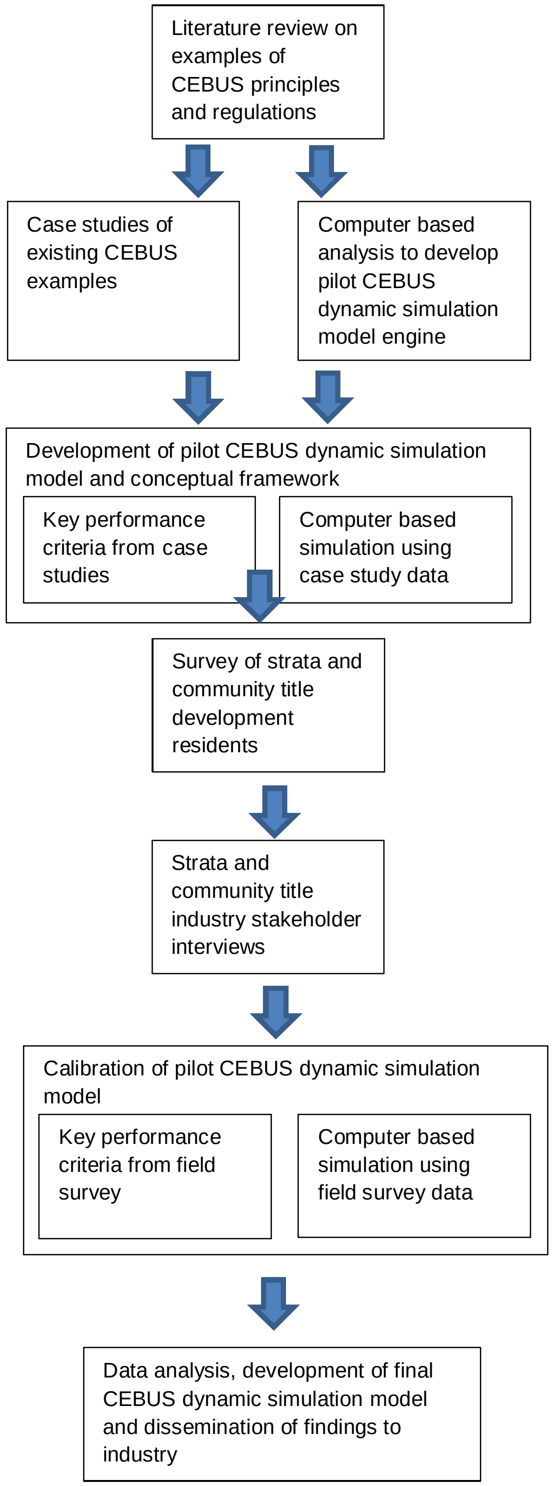


Figure 3. The overall research approach

Development of the pilot CEBUS Dynamic Simulation Model and Conceptual Framework

Using the data provided from the preceding desktop research and document study, a spreadsheet simulation was then developed in accordance with the preceding research methodology for each of the renewable fuel and vehicle types as shown in the solar PV / battery electric vehicle example in Table 7 which provides the ñengineòfor the pilot CEBUS Dynamic Simulation Model:

Table 7. Dynamic Simulation Model for the Solar PV / battery electric vehicle CEBUS type

Mean data for the key data input variables was then collected from the on-line survey of residents from a representative sample of the 690 known strata and community title developments in the Brisbane urban and peri-urban areas which have been identified as being in ñmortgage stressòand ñoil dependentò (Dodson & Sipe, 2008) together with having congested car parking at local public transport nodes (Translink, 2010). This data was then combined with data from relevant local meteorology, vehicle manufacturer and banking web sites for entry into the pilot CEBUS Dynamic Simulation Model to generate utilities and personal transport cost comparison graphs for review in the subsequent data analysis section. It should be noted that this initial model was calibrated for strata and community title developments in the South East Queensland region only and is therefore limited for use in comparing CEBUS design options for this particular housing type in this specific region for the purpose of this study.

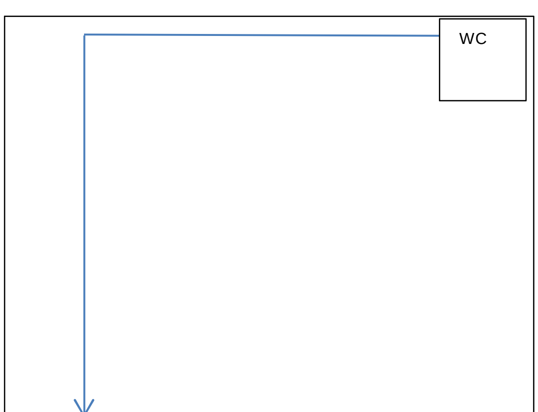
Based on review of the pilot CEBUS Dynamic Simulation Model key data input variables and the resultant key performance criteria outputs in Figure 4, the initial CEBUS Conceptual Framework was then developed using the following three key design criteria:

- Strata and community title development type ie low, medium or high density with low density defined as single storey with up to 15 dwellings per hectare, medium density defined as up to three storey walk-up, without a lift, with up to 80 dwellings per hectare and high density as greater than three storey, with a lift and greater than 80 dwellings per hectare (Newton & Tucker, 2009). This has a direct influence on the common area power and hot water usage together with the number of residents who are likely to participate in the proposed public transport node carpool scheme;

- Utilities type ie solar PV, biogas or hydrogen. This is determined by the availability of roof area, quality of effluent, local rainfall and sun hours which need to be balanced against forecast demand for the public transport node carpool scheme seats and common area power and hot water usage, so as to minimise the cost for common area hot water in $/litre and common area electricity in $/kWh;

- Vehicle type ie battery electric vehicle, compressed biogas vehicle or fuel cell vehicle together with the number of seats, which will be determined by the utilities type and also forecast demand for the public transport node carpool scheme, in order to provide the lowest possible $/km cost for commuters using the scheme.

Simple line diagrams were also produced for each of the renewable fuel and vehicle types, as shown in the biogas / compressed biogas vehicle example in Figure 4, in order to illustrate the fundamental operating principles of each CEBUS type:



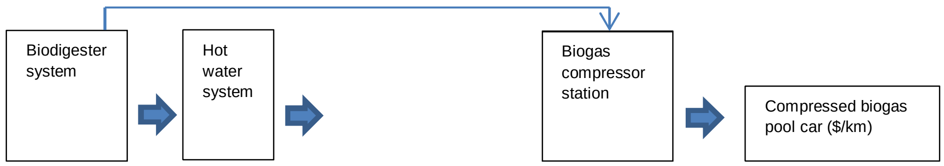


Figure 4. Line diagram for biogas / compressed biogas vehicle CEBUS type

Survey of Strata and Community Title Development Residents

The next step in the research program involved an on-line survey of strata and community title development residents in order to quantify their current utilities and transport costs and usage whilst seeking their opinions on the likely uptake of and potential operational problems associated with deployment of a CEBUS strategy within their strata community. The survey responses are summarised in Table 8:

Table 8 Responses from survey of strata and community title development residents

Data Analysis and Preliminary Findings

The mean data from the strata and community title residents survey was then used to populate the Dynamic Simulation Model for each CEBUS type in order to generate the potential utilities and personal transport cost savings / increases graphs as shown in Figures 5 to 7:

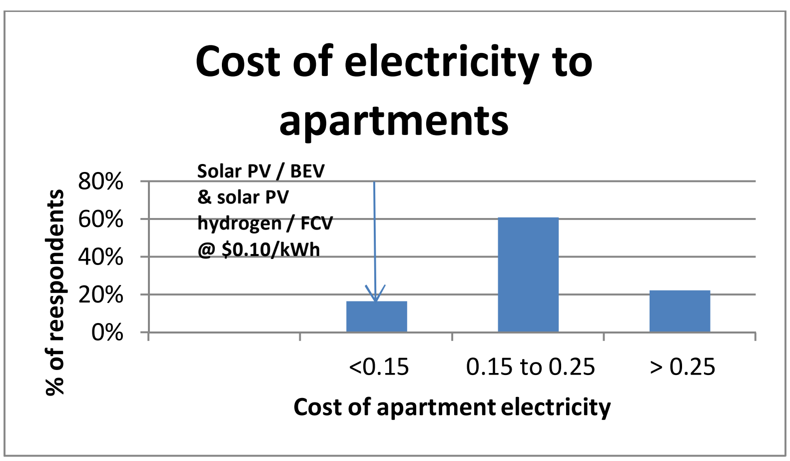


Figure 5. Cost of eletricity

The data in Figure 5 shows that the mean cost for electricity in the sample from the population of strata and community title developments is $0.20/kWh whilst both the solar PV / battery electric vehicle and solar PV hydrogen / fuel cell vehicle CEBUS types offer a lower electricity cost of $0.10/kWh.

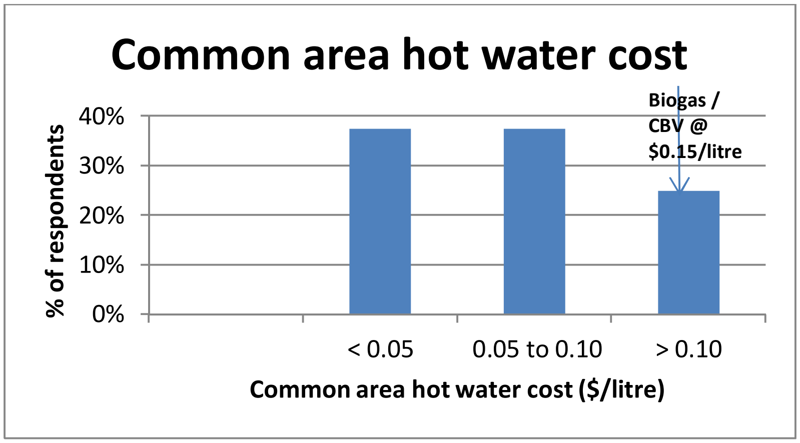


Figure 6. Hot water costs

The data in Figure 6 shows that the mean cost for hot water in the sample from the population of strata and community title developments is $0.075/litre whilst the biogas / compressed vehicle CEBUS type offers a higher hot water cost of $0.15/litre.

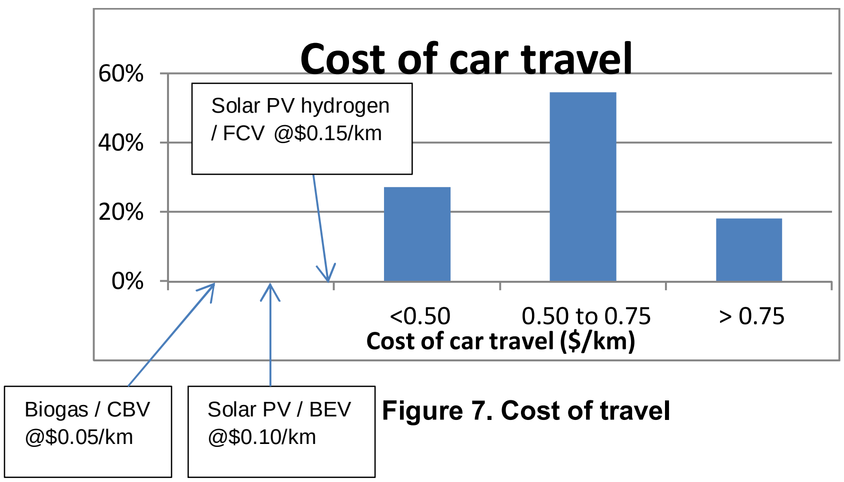


Figure 7. Cost of travel

The data in Figure 7 shows that the mean cost for personal transport in the sample from the population of strata and community title developments is $0.625/litre whilst the biogas / compressed vehicle, solar PV / battery electric vehicle and solar PV hydrogen / fuel cell vehicle CEBUS types all offer lower personal transport costs of $0.05/km, $0.10/km and $0.15/km respectively when operating in car pool mode.

Review of these initial dynamic simulation model outputs highlights the fact that both the solar PV / battery electric vehicle and solar PV hydrogen / fuel cell vehicle CEBUS types offer a 50% saving in electricity costs when compared with the current mean electricity cost for the ñstressedò strata and community title developments in the Brisbane urban and peri-urban regions, however, the biogas / compressed biogas vehicle CEBUS type dynamic simulation model output indicates a 100% increase over the current mean hot water cost for these same developments.

These outputs also highlight the fact that all three CEBUS types offer potential savings in personal transport costs when compared with current mean personal transport cost, with the biogas / compressed biogas vehicle type offering a 90% saving, the solar PV / battery electric vehicle type offering an 80%

saving and the solar PV hydrogen / fuel cell vehicle type offering a 70% saving when each are used in a car pool mode.

Given that these preliminary findings indicate that hot water costs are actually higher for the biogas / compressed biogas vehicle CEBUS type and that no fuel cell vehicles are commercially available as yet in Australia, it was decided that the strata and community title test site will utilise the solar PV / battery electric vehicle CEBUS type. It should also be noted that the solar PV / battery electric vehicle CEBUS type appears to offer the lowest total GHG intensity based on the data from Tables 3 and 4.

Conclusions

The research to date has provided new knowledge for the academic community and construction industry in terms of the development of a working pilot CEBUS Dynamic Simulation Model which has been populated using mean data from the strata and community title development residents survey to highlight potential utilities and personal transport cost reductions available in the local context, using the solar PV / battery electric vehicle or “SolaDrive” CEBUS type in the first instance, of 50% and 80% respectively. This CEBUS type also provides for reduced greenhouse gas intensity when compared with coal based grid electricity and fossil fuel type internal combustion engine vehicles.

A pictorial conceptual framework for each of the CEBUS key design criteria has also been developed, together with line diagrams for each CEBUS type, which will be utilised in the next stage of the research to determine property development and construction industry stakeholder views on the potential for widespread adoption of this concept in strata and community title developments, as a means of contributing to the development of affordable and sustainable housing stock.

Development of the CEBUS methodology has also highlighted the potential benefits of combining individual best practice sustainable design elements and transit oriented development strategy, via integrated development techniques to deliver effective initial construction cost savings of up to 35%.

Although the initial CEBUS Dynamic Simulation Model is calibrated using mean utilities and transport data for strata and community title developments located in the South East Queensland region of Australia, it can easily be adapted for use in other regions throughout Australia and internationally through the adjustment of renewable energy availability, utilities and transport costs together with commuter travel distance data in accordance with local conditions. Higher natural gas costs for water heating and/or the commercial availability of fuel cell vehicles may in fact recommend use of the biogas / compressed biogas vehicle CEBUS type (“BioDrive”) and/or solar PV hydrogen / fuel cell vehicle CEBUS type (“HydroDrive”) in preference to the “SolaDrive” CEBUS type as recommended for use in the South East Queensland region.

Following completion of the property development and construction industry stakeholder in-depth interviews, a trial of the “SolaDrive” CEBUS type will be conducted at a local strata and community title development which will inform a subsequent case study to disseminate the final research findings and conclusions to the academic community and construction industry.

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